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The Polar Ice Prediction System (PIPS) is an operational numerical model used for the daily prediction of ice drift and ice growth/decay in the arctic. PIPS has as its basis the Hibler ice model and is driven by atmospheric forcing, geostrophic ocean currents and deep oceanic heat fluxes. The model is initialized once per week by the Naval Polar Oceanography Center's (NPOC) analysis of ice concentration. The existing method of initialization completely replaces the model derived concentration with the NPOC data. This study describes a new method, nonlinear regression, of blending the continuity equation and available data with the model derived concentration field to obtain a more realistic updated field. The final estimated ice concentration is the best fit among the equation and data. Since the NPOC ice edge and open water are based on field observation, they are assumed reliable and a weighting method is used to constrain them in regression. Errors which might occur in the digitized NPOC ice edge could be adjusted by weighting atmospheric forcing and/or the model derived concentration. Another advantage of the regression method is to include more available, related data such as the satellite ice concentration from the Scanning Multichannel

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A Blending Technique For Data Assimilation Into An Arctic Sea Ice Model

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ABSTRACT

The Polar Ice Prediction System (PIPS) is an operational numerical model used for the daily prediction of ice drift and ice growth/decay in the Arctic. PIPS has as its basis the Hibler ice model and is driven by atmospheric forcing, geostrophic ocean currents and deep oceanic heat fluxes. The model is initialized once per week by the Naval Polar Oceanography Center's (NPOC) analysis of ice concentration. The existing method of initialization completely replaces the model derived concentration with the NPOC data. This study describes a new method, nonlinear regression, of blending the continuity equation and available data with the model derived concentration field to obtain a more realistic updated field. The final estimated ice concentration is the best fit among the equation and data. Since the NPOC ice edge and open water are based on field observation, they are assumed reliable and a weighting method is used to constrain them in regression. Errors which might occur in the digitized NPOC ice edge could be adjusted by weighting atmospheric forcing and/or the model derived concentration. Another advantage of the regression method is to include more available, related data such as the satellite ice concentration from the Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave Instrument (SSMI).

DATA:

We have used the PIPS model grid covering the central Arctic, the Barents Sea, and the Greenland Sea down to approximately 65°N latitude. The region is discretized into 47 by 25 grids [Preller, 1985]. Of the 1175 possible grids, only the 721 "sea grids" (as opposed to "land grids") on which ice can grow, decay and move, are used. Each grid is approximately 127 km square.

Fig. 1 is a contour map of the digitized NPOC ice concentration on November 26, 1985 interpolated to the PIPS grid. This field is a subjective blending of a number of different data sources. Conventional field observations include data from shore stations and ships. Satellite data are AVHRR from the NOAA polar orbiter, NASA Nimbus 7 SMMR, and visible imagery from the DMSP. Over the past two years, Geosat altimeter ice index data and more recently DMSP SSMI data have been additional data sources. Limitations, primarily due to the resolution and wave length of the data (such as cloud limitations), may strongly influence the accuracy of the NPOC ice concentration analysis. Fig. 1 shows ice concentration in the central Arctic to be 100%. South of the ice edge, the ice concentration varies sharply, often from 80%-100% in one region to zero in the adjacent region. Thus the NPOC analysis, particularly at the ice edge, is represented as a sharply discontinuous field. Note that the tightly packed contours at the ice edge in Fig. 1 are an artifact of the plotting package used to create this figure.

Fig. 2 is the PIPS model derived ice concentration field on November 19, 1983. The first test data set of atmospheric forcing available for driving the PIPS model was from the year 1983. However, the first digitized NPOC analysis became available in 1985. For the purpose of testing this data assimilation scheme, it is sufficient that the general features of the ice concentration from these two years (1983 and 1985) were similar in the central Arctic, but some inconsistencies occurred at ice edge. As in the NPOC data, the model concentration field shows 100% ice concentration in the central Arctic and 15% south of the ice edge. This is minimum value of ice concentration used by the model, for ice thicknesses from 0 to 0.5 meter, and is chosen strictly for numerical purposes [Hibler, 1979]. The largest difference between the model concentration and the NPOC data occurs in the Greenland and Barents Seas. The ice edge in these regions is located much farther south in the model than in the data.

It should be noted that Figs. 1 and 2 are representative of an extreme inconsistent situation at ice edge. In this test, the PIPS model has never previously been updated by any data. In an operational situation, when PIPS is updated weekly, it seldom diverges from the NPOC analysis to the extent seen in Figs. 1 and 2. Therefore, we have chosen a rigorous test case for the new blending technique.

RESULTS:

Fig. 3 shows the estimated ice concentration in the Arctic using the nonlinear regression method discussed in Cheng and Preller's paper [1990]. The ice concentration is assumed to be in equilibrium and the continuity equation is integrated over a time step. In the central Arctic area, the ice concentration is about 100%, similar to both the NPOC analysis (Fig. 1) and the model concentration (Fig. 2). The estimated ice edge in the Greenland and Barents Seas is much smoother than the NPOC ice edge (Fig. 1) and similar to the model ice edge (Fig. 2). The smooth part of the estimated ice edge is influenced by both the continuity equation and the model derived ice concentration. The extended ice edge might be dominated by a positive ice growth rate mainly due to atmospheric forcing in November (Fig. 4), which could be 10 to 50 times greater than that due to ice advection. As a result, the final estimate has extra ice south of the NPOC ice edge.

Since the Arctic ice concentration field has been discretized into 721 grids, we can weight each individual field differently if necessary. For example, if we believe that the NPOC ice edge and open water data are more reliable than that from the PIPS model, they can be weighted to make the final estimate consistent with them. This estimated ice edge, except for a few grids north and south of it, is similar to the NPOC data. This technique of weighting data could be applied to any data set incorporated into the regression scheme. If, for example, we have high confidence in passive microwave data in the central Arctic but low confidence at ice edge and in open water, then we would weight the data more in the former grids than in the latter ones.

A weighted residual analysis shows 54.5% of all 2163 residuals are greater than +0.25 (in the same unit as ice concentration) because of a great portion of positive residuals from the PIPS model derived concentration and the continuity equation. This implies that the final estimate of ice concentration in general (especially south of the ice edge) is less than and disagrees with what the continuity equation and the PIPS model derived concentration expect. Note that the NPOC ice edge and open water have been weighted to force the final estimate to be consistent with them. The bias is

anticipated when part of data sets is believed more reliable and is weighted more than the others. Cautious data examination should be taken before applying the weighting technique. Please note that the detailed data editing for each grid may improve the final estimate. However this data assimilation method has been designed for an automated data processing to be used in a daily ice forecast, where manual data editing for each grid would be impractical.

A test data set of SMMR ice concentration values from November 26, 1985 was interpolated to the PIPS model grid. The SMMR data contained more variability in the concentration of the central Arctic than either the NPOC or the model data. Values of the ice concentration between 90 and 100 % are found in parts of the central Arctic, Chukchi and east Siberian seas. When the regression technique is applied to the NPOC, SMMR and model data along with with the continuity equation using equal weighting of all data, the structure of the SMMR data is apparent in the final estimate both in the central Arctic and at the ice edge. If the SMMR data is weighted in the central Arctic and the NPOC data weighted at the ice edge, the corresponding final estimate would be considered the best estimate based on our confidence in the data.

The NPOC assumption of 100% ice concentration in the central Arctic is likely inaccurate in summer and does not account for ice opening in winter due to wind blowing from the Novaya Zemlya island. The assumed ice concentration can be modified by weighting the continuity equation and/or the PIPS model concentration inside ice edge. The same weighting method may also find possible errors in the NPOC ice edge and adjust them according to atmospheric forcing and/or model derived concentration.

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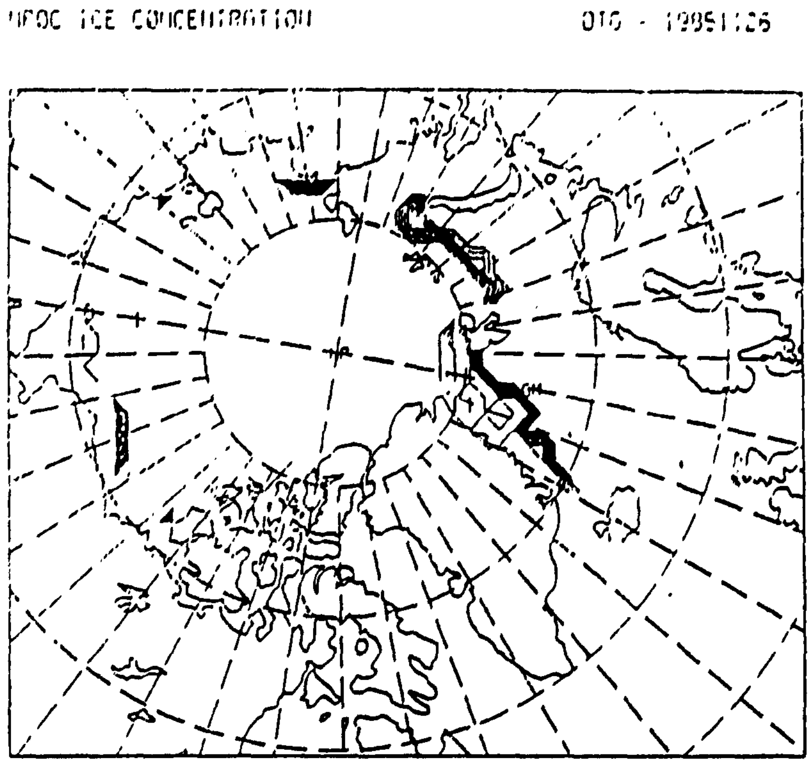

Fig. 1 An ice concentration contour plot of the NPOC weekly analysis on November 26, 1985. The contour interval represents 10% of ice concentration.

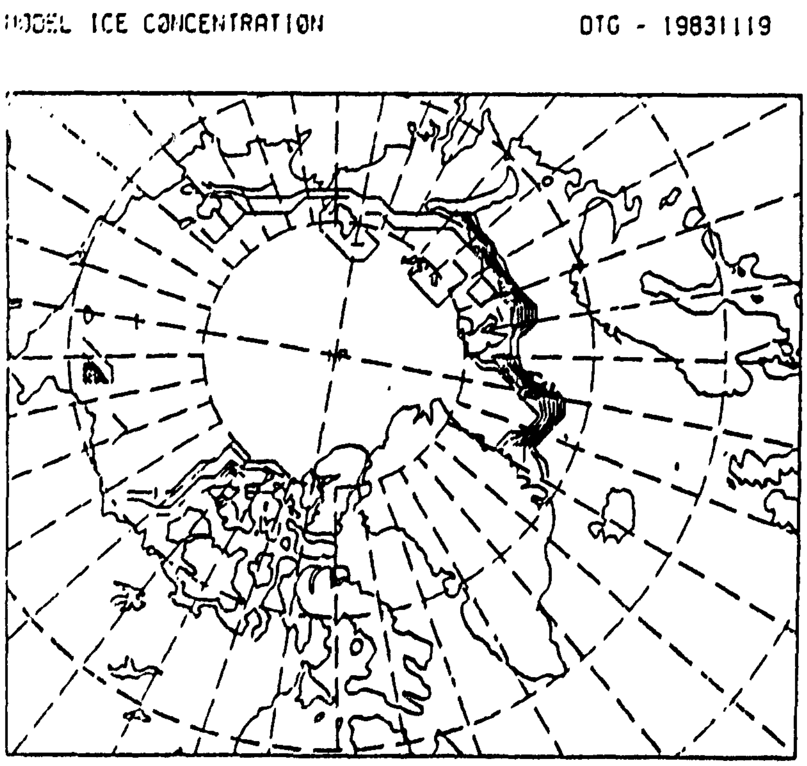

Fig. 2 An ice concentration contour plot of the PIPS model on November 19, 1983.

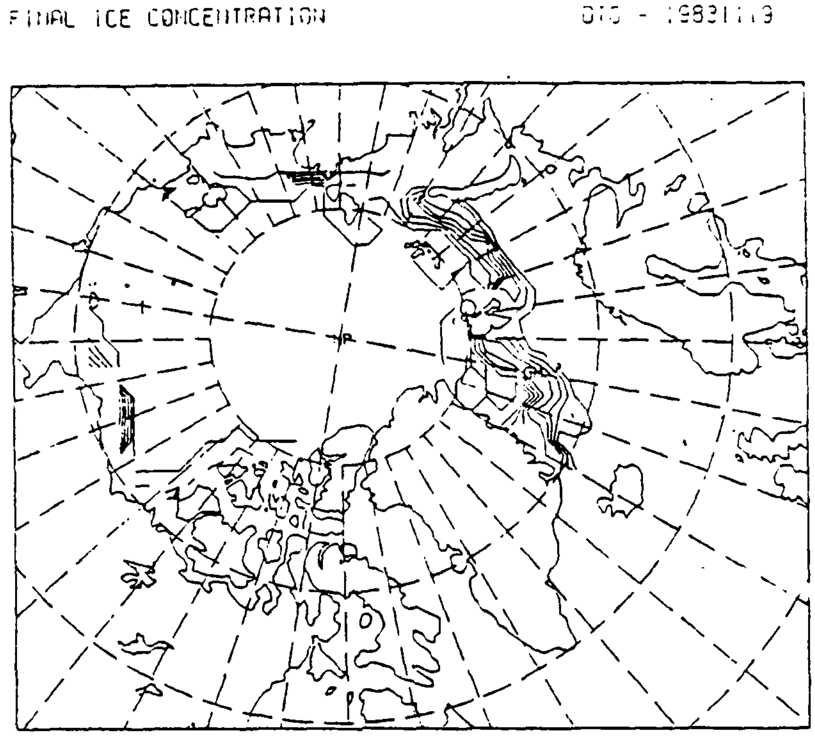

Fig. 3 An ice concentration contour plot of the final estimate from the regression using the continuity equation, the NPOC data, and the PIPS model.

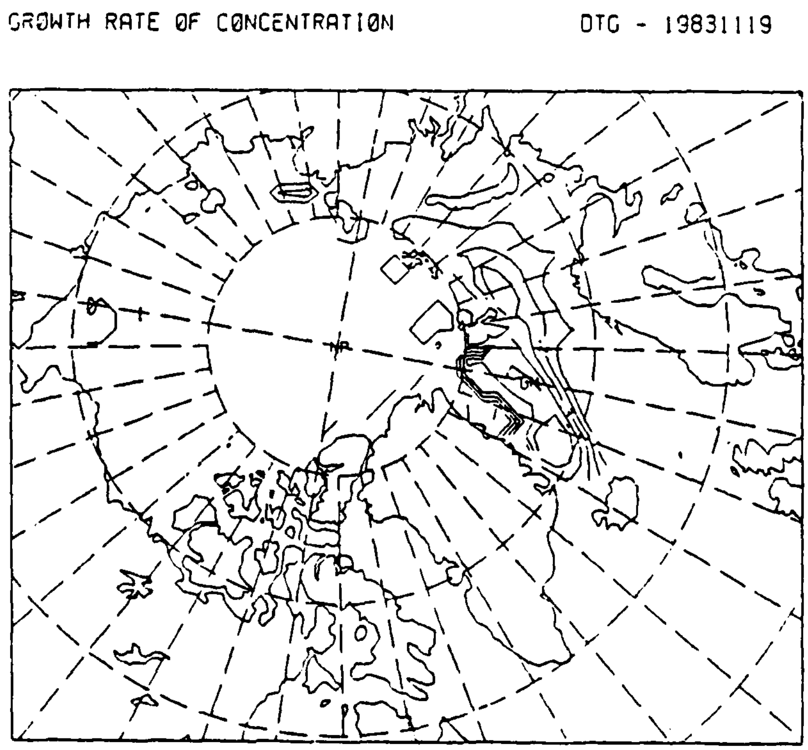

Fig. 4 The growth rate of ice concentration, S_A, due to the thermodynamic effect of atmospheric forcing, ocean current, and heat